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History of the project and start-up phase results:[1]

This digital humanities project was devoted to the development and use of a new programming language vernacular, based on geometric principles of ruler and compass construction, for designing string instruments according to the traditional methods based on François Denis's definitive monograph, **Traité de lutherie: the violin and the art of measurement** (ALADFI, 2006). The impact of Denis's **Traité** has been profound: the catalogue for the 2013 exhibit of Stradivari instruments at the Ashmolean Museum in Oxford included the unmistakable homage to his pioneering work: *"It is now recognized that what first distinguished Cremonese instruments from those made in other centres was a geometrical formality of design and proportion borrowed straight from the architects, painters and many other designers and craftsmen of the Renaissance."* The software can be used for designing outlines, scrolls, ff-holes, and as a tool for research into the history and evolution of string instrument forms. Future work will include extending it in various ways, including to arching, and to build a compiler that can translate high-level geometric descriptions (what's in the "mind's eye" of the luthier) into toolpath directions for a CNC (computer numerically controlled) router, automating important (but not all!) aspects of the luthier's skilled hand.

The beginning of the project saw the initial formulation of what we call the *geometry engine*. It is, in effect, a programmable straightedge and compass machine, where the user writes code describing geometric constructions. The programming "front end" of the user's *source code* is totally Euclidean, in the vernacular of the original knowledge, while the computational "back end" of the *target code* is entirely Cartesian, in the numeric, rectilinear language of computation. Like any good programming system, the goal is to let the user express what is viewed important (geometry), where the implementation hides unnecessary detail (numbers and ancillary calculations).

There are any number of lovely books that describe such Euclidean constructions in a colloquial language, which can then be programmed directly.[2] A central, core thesis of the Coates and Denis monographs (among others) is that string instruments were designed and drawn *proportionally*: parameterized from one initial, physical distance, the geometric construction followed entirely from straightedge and compass constructions of points, lines, circles, arcs, and intersections between them.

The practical core of François Denis's **Traité de Lutherie** is a similar description of seven different string instrument models by famous makers; the language can then be used to embody the constructional knowledge expressed in these descriptions. It was an epiphany to recognize that a significant component of this book was, in essence, an informally written computer program. Moreover, the programming language can elide—with complete precision—common patterns of design, abstracting over them with appropriate parameterization.[3] As a consequence, the description of how to draw these instruments can be given with a kind of hierarchy that emphasizes salient aspects of the design. (Think of the programming language description as a kind of high-level instrument specification, and the underlying straightedge and compass constructions as a sort of low-level machine language.)

This software was used to code many of the designs described, in detail, in Denis's book.[4] We proceeded from following these "recipes" to a kind of "cooking" on our own: we took measurements from high-resolution, low-parallax photographs of several Stradivari violoncellos[5]: the *Mediceo*, the *Cristiani*, and *ex-Paganini, Countess of Stanlein*, reverse engineered the data following the Denis methodology, and produced geometry engine code for straightedge and compass constructions of these instruments.

[1]"We" describes here work done by the principal investigator (Mairson) during the start-up phase supported by NEH ODH and also by NSF. A web site containing most all results and deliverables produced during the start-up phase is `www.cs.brandeis.edu/~mairson/TDL`.

[2]See, e.g., Andrew Sutton, **Ruler and Compass: Practical Geometric Constructions** (Bloomsbury, 2009), and Robert Vincent, **Geometry of the Golden Section** (Chalagam, 2014).

[3]This is revealed knowledge in courses on software design; see e.g., Harold Abelson and Gerald Sussman, **Structure and Interpretation of Computer Programs** (MIT Press, 1985), a course that Mairson has taught for years. (See Appendix.)

[4]See `www.traitedelutherie.com`: instruments by Amati, Guarneri, Montagnana,. . .

[5]These renowned instruments are typically named after famous musicians who played them, e.g., the *Cristiani* after Lise Cristiani, for whom Felix Mendelssohn composed the *Song Without Words*.

The geometry engine was also used, in a kind of proof of concept, as an investigative tool to understand more about the history and evolution of instrument design, an inquiry we like to call "computational art history".[6] Our initial focus on Stradivari violoncellos was in part motivated by Denis's proposition that this maker marked a transition from the "classic" to "romantic" understanding of forms. What, then, could Stradivari have understood about classical, proportional design—could he have conceived of these forms purely through that geometrical approach? One way to address this possibility was to try ourselves. Earlier violoncello design, we thought, was likely to tend to be more traditional than violin design because making a cello takes so much longer than making a violin, and consumes more resources. Violins—smaller, cheaper, with more rapid production—are a more likely venue for experimentation with novel, alternative technology.

Stradivari violoncellos changed markedly over four decades, commensurate with the improvements in string technology that allowed shorter strings with greater resonance, and the transition of the violoncello from providing *basso ostinato* in church processionals to being a virtuoso instrument. His most celebrated, canonical model, and the one largely made today, was the *forma B*, played by Mstislav Rostropovich (the *Duport*), Yo-Yo Ma (the *Davidov*) Bernard Greenhouse (the *Countess of Stanlein*), etc. Where did the idea for the *forma B* come from? What was the point A, the penultimate, mythical *forma A*, that got Stradivari to point B, the *forma B*? We tried to explain the evolution of this form from principled modification of Stradivari's earlier *Mediceo* instrument: proportionally reduced but virtually identical in the upper two bouts, with an extension of the curves in the lower bout, and longer tangents at the lower corners of the bout. (The *bouts* refer to the top, middle, and lower *sections* of the instrument.) We completed an instrument drawing inspired by the *Stanlein* and based on this hypothesis; it was built by luthier Todd Goldenberg this year.

Data for these kinds of analytic reconstructions of instrument forms come from different sources, including measurement of instruments, photographs, and CT imagery. Each source comes with its own challenges and risks of error. We focused particular attention on the *Cristiani*, a transitional instrument from larger models to the canonical *forma B*. We did several iterations of the drawing, finally with CT data. It became evident that the *Cristiani* and the *Castelbarco* violoncello (now in the Library of Congress) had identical forms and were made from the same internal mold.

Much of this work was presented in conference at the Violin Society of America's annual meeting in 2014, and at the ACM International Conference on Functional Programming in 2013.[7] These presentations in front of (respectively) programming language and lutherie professionals were augmented with more practical workshop presentations on design, and how to use the software. In September 2014, we organized a visit by François Denis to the North Bennet Street School, a vocational arts institute, to present his drawing method to students in the violin making program.[8] In January 2015, we organized a two-day workshop at Brandeis University for a dozen-odd luthiers on using the geometry engine.[9] This was a (largely successful!) exercise in seeing whether a group of luthiers could write code to design instruments; participants completed code for a drawing of a violin by Andrea Amati, interpreting directions from Denis's book in the formal language of the geometry engine. It was followed in the summer by a presentation at the Oberlin Violin Workshop[10], a remarkable two-week annual by-invitation gathering of 60 luthiers from around the world,

[6] See e.g., Philip Steadman, **Vermeer's Camera** (Cambridge, 2002). We're certainly not the first to use this term, but we have a specific, individual idea of what this term could mean.

[7] See for example the review ("Fun in the afternoon" at `wadler.blogspot.com/2013_10_01_archive.html`) of our paper, *Functional Geometry and the Traité de Lutherie*, by Prof. Philip Wadler (U. Edinburgh). The paper was chosen as a research highlight by the Association for Computing Machinery see `www.sigplan.org/Newsletters/CACM/Papers`. The project was highlighted in the **Atlantic Magazine** (`www.theatlantic.com/technology/archive/2014/04/how-high-frequency-trading-computers-see-new-york/359984/`), and presented also at seminars given at the Humanities Center at Brandeis, the University of Maryland, U.C. Berkeley, and NEH.

[8] We [HM] sponsored his visit to take the course and learn more about the method ourselves. We also visited him for a week in July 2014 to learn more about his methods.

[9] `www.cs.brandeis.edu/?p=618`.

[10] `www.oberlinviolinmakers.org`, and especially the video `https://vimeo.com/70135675`.

which was followed with individual tutorials for luthiers who wanted to learn more.[11]

The Oberlin visit was particularly exciting: our drawing of the *Cristiani* interested many luthiers, not only because it has iconic status among the Stradivari violoncellos, but also because our analytic reconstruction of it was a proportional reduction in size to modern, quasi-*forma B* dimensions. As a consequence, there was renewed interest in building the model—which is why we [HM] did it in the first place.[12] Benjamin Ruth, a renowned American luthier, has mischievously referred to this reduced-size *Cristiani* as the Stradivari *forma P* violoncello, analogizing the *forma B* with the "long form" violins made by Stradivari, and the so-called "P-form" violins that followed them.

Oberlin attendees Paul Crowley and David Polstein took our PDF files, and used them with the Rhino 3D modelling software to produce files directing a CNC (computer numerically controlled) router. An Oberlin-area shop with CNC equipment was found, and in the space of two days, roughly 40 internal molds and templates were produced for Oberlin workshop participants who paid $150 each to the shop for the instrument-making infrastructure. We expect to see numerous *Cristiani* models this spring. In addition, we're starting to think about a similar geometric description of *arching* of front and back plates, where a compiler would translate this high-level conception to toolpaths for a CNC router.

This conclusion was a very satisfying summary to an ensemble of work: of François Denis's remarkable historical research, and its practical significance (namely, *here's how to draw violin forms*), of the software development that allowed this knowledge to be automated, embodied, and transmitted, of the focus on the *Cristiani*, long thought of as a prescient design move towards the *forma B* model, and to the final step where practical, historically appropriate artifacts could be provided to instrument makers.

Digital humanities is, at its core, about building things. These luthiers could appreciate the essential features of the chain of interrelated constructions: of theories, of historical methods, of software, of luthier infrastructure. They clearly realized that the software component was essential in expediting a new approach to the understanding, design, and making of string instruments.[13]

Our intention is that this digital humanities project can provide an analytic, computational foundation for studying aspects of this design tradition and its associated art history—not simply as a form of automation, but through an ensemble of intellectually precise, linguistically articulate descriptive tools, with examples of their use. The Renaissance quadrivium of arithmetic, geometry, music, and astronomy was anticipated by Pythagoras and immortalized by Plato. Replacing astronomy with computation results in a new quartet of complementary analytical and creative disciplines, spanning the humanities and sciences, and forming together an integrated subject.

[11] Next summer, we [HM] are invited as a regular participant, to learn more about violoncello making, and to teach luthiers more about coding and design.

[12] The redesigned *Cristiani* has a body length of 740mm, shorter than the *forma B* models (typically around 755mm), but the reduction is principally in the lower bout; dimensions and relative proportions in the upper bouts resemble the *forma B* models very closely.

[13] See the related essay by Steve Ramsay, *On building*, at `stephenramsay.us/text/2011/01/11/on-building/`, following his presentation at the "History and Future of Digital Humanities" panel at the 2011 MLA.